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HENDRIK VAN ARK

Request for a Bridge Design

"Every so often there's a rush job that has you working through Saturdays," Mr. Hendrik Van Ark observed. As a civil engineer in the Structural Division of the Lancer Construction Company he had been called to a meeting on Thursday, April 13, 1967 concerning a new two unit, 1,500 megawatt steam power plant being built by Lancer. The question which the group had for him was how to bridge a creek lying between the construction site and a county road which presumably would be used in trucking men and equipment to the site. An independent consulting engineer, Mr. Brynne, had recommended building a 100 foot "composite steel girder" bridge because, he said, it should be possible to obtain girders quickly. Mr. Van Ark was asked to consider the recommendation and proceed as he thought appropriate. "Normally I wouldn't be called into a meeting like that where everyone else was a consultant or chief engineer of some department, but this bridge design was needed fast to avoid delaying other work."

Prepared in the Design Division, Department of Mechanical Engineering by Karl H. Vesper with financial support from the National Science Foundation.

A plan indicating routing for the new access road to the site was available (Exhibit 1), and from conversation at the meeting Mr. Van Ark had learned further facts about the job. He was told that heavy pieces of machinery to be brought to the site would include a rotor weighing roughly 100-150 tons, stator weighing 200 tons plus casings and steam drum which might weigh from 50 to 80 tons each.

Men and equipment were at present reaching the site by dirt roads and small farm bridges. But for hauling larger loads of cement and other materials these were considered totally inadequate. The standard two lane county road which ran with its center line parallel to and approximately 20 feet from the edge of the creek was being resurfaced to enable it to support traffic including the largest conventional diesel truck-trailers ("semi"), one of which might weigh up to 72,000 pounds fully loaded, be eight feet wide and 50 feet long with a minimum turning radius capability of 40 to 50 feet. The new bridge was to allow such trucks to reach the power plant site from the county road.

"The State Highway Code doesn't say much about the maximum load that can be carried by truck," Mr. Van Ark continued. "But the AASHO (American Association of State Highway Officials) code recommends a limit of <u>20</u> tons. State highway officials can impose limitations sometimes even when a code does not, so I think it pays to be conservative."

His next task, as he saw it, was to do a brief analysis for deciding which of several types of bridges would be best. He thought the total cost of the bridge, which he expected would be around $100,000, did not justify an extensive study, but he pointed out that unless some study was used there might be an uneconomic choice of alternative which would later reflect poorly upon Lancer as a construction company and damage its reputation. He noted that since the bridge was intended for use in construction, which was already beginning, it was desirable that his design be done quickly.

Hendrik was in the middle of other work when he was called in to design the bridge, and it was not until Saturday that he had enough free time to begin. He then started with some rough computations to estimate costs for several alternative types of bridges, including the one recommended by Mr. Brynne. "Once the location is decided, the first thing to do is figure out what type of bridge it should be," he observed. "There are several possible steel bridges, and there are also some using prestressed concrete girders. I asked about the location of shops for making girders, and it turned out that there were shops within 500 miles for making either steel girders or concrete ones. I phoned one of them, who said he could guarantee delivery within a month."

"Mr. Brynne thought steel girders would be best. He's an authority, particularly on bridges and on wind loading of structures, who has many years of experience with these things. He comes in every Thursday and discusses whatever problems we bring up. I have experience too, but mine

is more in structures for nuclear power plants. I don't pretend to be a super-duper specialist, but just design for whatever comes along. There's more variety that way. On bridges I generally like to get Mr. Brynne's ideas first, then check them out and do my own thinking from there. Some of the other engineers prefer to do their own thinking first and then check with him. It's mostly a matter of taste.

"There are generally two types of concrete girders, the 'pretensioned' kind and 'post-tensioned'. The pretensioned type is completely prepared in the shop for installation, whereas with the post-tensioned you have to do the tensioning in the field after it is in place. Sometimes when the site is too far from a shop or when the girders have to be too long or heavy to transport it's better to cast them in place and then tension them. But this takes more time, so I think we should only consider pretensioned girders if we use concrete. An advantage of concrete girders is that they should be cheaper to maintain, because they don't have to be painted every two or three years."

In comparing concrete and steel girders Mr. Van Ark saw a number of alternatives open, and his first step toward making the choice was to draw from the Lancer Company library a copy of the "Manual of Bridge Design Practice" (prepared by the State of California Division of Highways).[1] "Handbooks are essential in this business," he commented, "so you don't spend all your time reinventing the wheel. Lancer Corporation has a collection of its own data on various topics, and generally each public agency has one or more manuals of its own particular set of rules and standards. They may overlap to some extent, but each will usually have its own peculiarities. For instance the highway engineers are normally more conservative than building engineers, and the railroad engineers are more conservative than the highway engineers; maybe because the things they build don't go out of style so fast and have to last longer."

"Manuals are especially useful for designing fairly standard structures like this bridge. Here we have parallel sides, square ends and a moderate length, so the handbook fits nicely. If I wanted to put in a curve or some unusual feature, the handbook wouldn't fit and I'd have to solve problems of loading and strength using basic theory."[2]

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[1]The Preface explains: "The graduate engineer is expected to be well grounded in the fundamentals of structural design, but until he gains practical design experience, he may encounter difficulties incorporating this fundamental knowledge into efficient and rational design procedures. The manual is intended primarily for the inexperienced bridge designer, but the older or more experienced engineer may find new ideas and methods which would be of value to him."

[2]Mr. Van Ark's education had included a degree in Civil Engineering from the Engineering College of the Academy of Arts and Technological College in Rotterdam. He worked as a structural design engineer for ten years before joining Lancer and had been with Lancer for six years as of 1967.

Mr. Van Ark began his computations with assumptions listed in his notes, which have been copied as Exhibit 3. Since the county road had two lanes, engineers at the meeting had said the bridge should also, and he estimated a deck width ("rail to rail" width) of 30 feet. The standard load carrying ability (denoted by H20-S16-44) he described as the heaviest one listed, and from experience he recalled that it was used often for roads leading to power plants. According to the Bridge Design Manual:

> "The H20-S16-44 load represents an approximation of a train which consists of a 20 ton truck preceded and followed by 15 ton trucks."

One question, as Hendrik saw it, was whether to use steel or prestressed concrete girders. Another was whether to use one span or three. He commented that freeway overpasses often used two spans with a pier in the middle because shorter spans could be lighter, cheaper and easier to put up. The possibility of using two spans across the creek he rejected, however, because of the difficulty and expense of constructing a pier in the center where there was always water. Whether the three spans should be separate or one continuous beam laid across intermediate piers was a question he chose to ignore for the moment and consider later only if the choice between one span and three was close. He thought a single beam laid across the piers rather than three separate beams might reduce the amount of steel required by roughly 10%. He also thought that in his first comparative cost estimate he would ignore costs of excavation and backfill needed for abutments at the ends of the bridge, of decking, and of transporting materials to the construction site. These expenses he expected would be roughly the same for any alternative.

His computations of girder costs for several alternatives are shown in Exhibit 3. Charts of the Bridge Design Manual on which they were based appear in Exhibit 4. A summary of his computations appears on the first page of his notes with blank spaces for the figures he thought should be calculated next. To compute the cost of abutments and piers he planned to use the creek profile drawing of Exhibit 2 and the Manual charts of Exhibit 5. He thought a "cantilever" type abutment would be suitable for ends of the span and that it would be alright to assume the center piers would be similar to hinged abutments in making computations for the three span design. The abutment height ("H" on the chart of Exhibit 5), he explained, should be measured up from a point roughly 3 or 4 feet below the surface of the ground. Below this point would be pilings on which the abutment rested.

"I think it's important to be organized and accurate about calculations like this," he said, "because you never know when you may have to back and check how you worked something out. The company regulations say all calculations are to be filed permanently and that we are supposed to keep them neat, but I'll bet less than 25% of the engineers do it."

"Once it is clear which type of bridge we should have I'll go on with more details of the design, such as how many piles to use for the abutments, and what pattern to place them in. It will probably take me one or two weeks to prepare a complete design which we can send out to subcontractors for bids. By then I'll have about 40 to 50 pages of calculations, at least two drawings plus a collection of other paperwork, such as standard specifications, purchase orders, memos and correspondence. Hopefully, construction on this bridge will begin by the end of May at the latest."

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Exhibit 1 - Map Showing Bridge and Plant Site

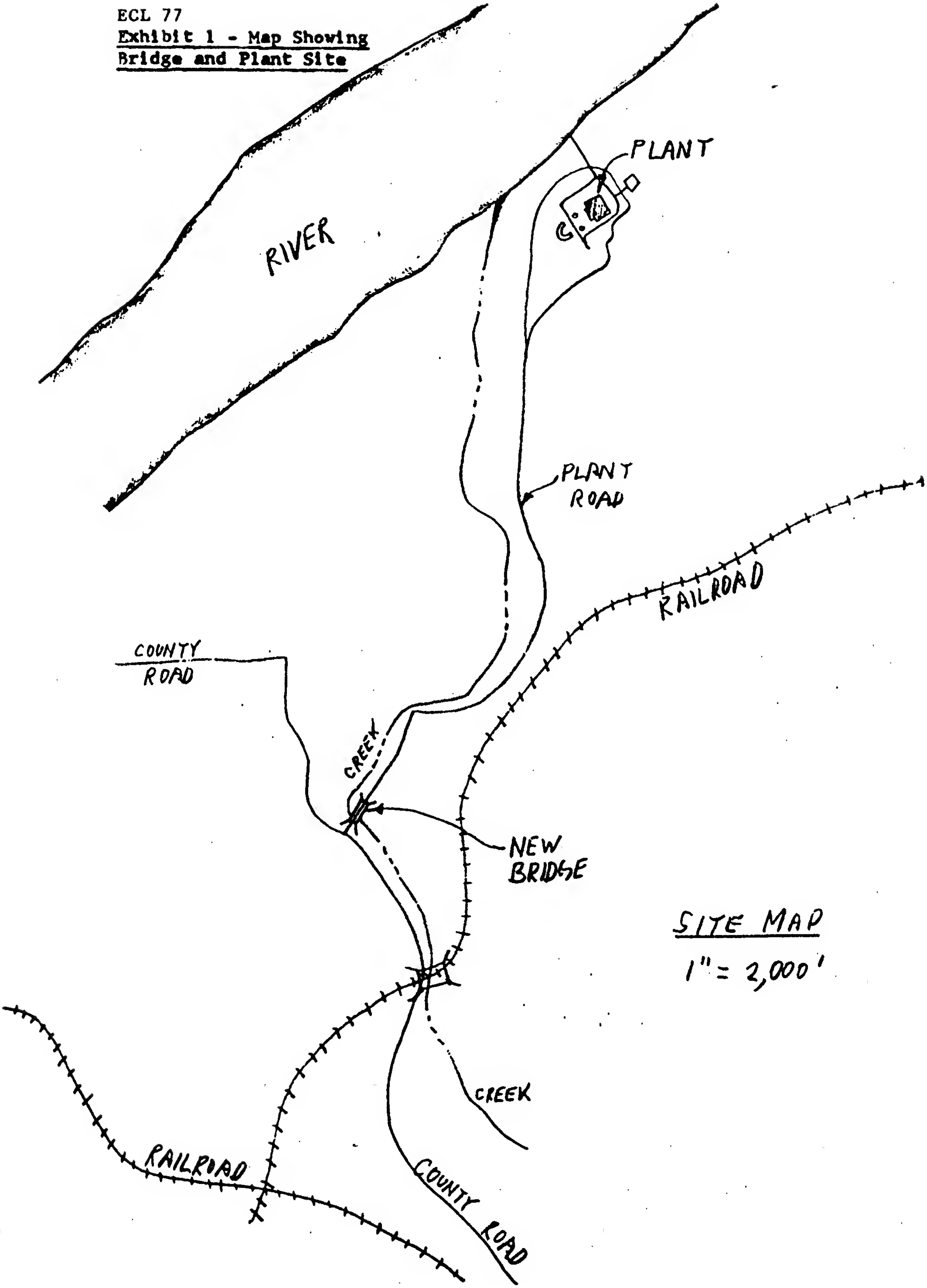

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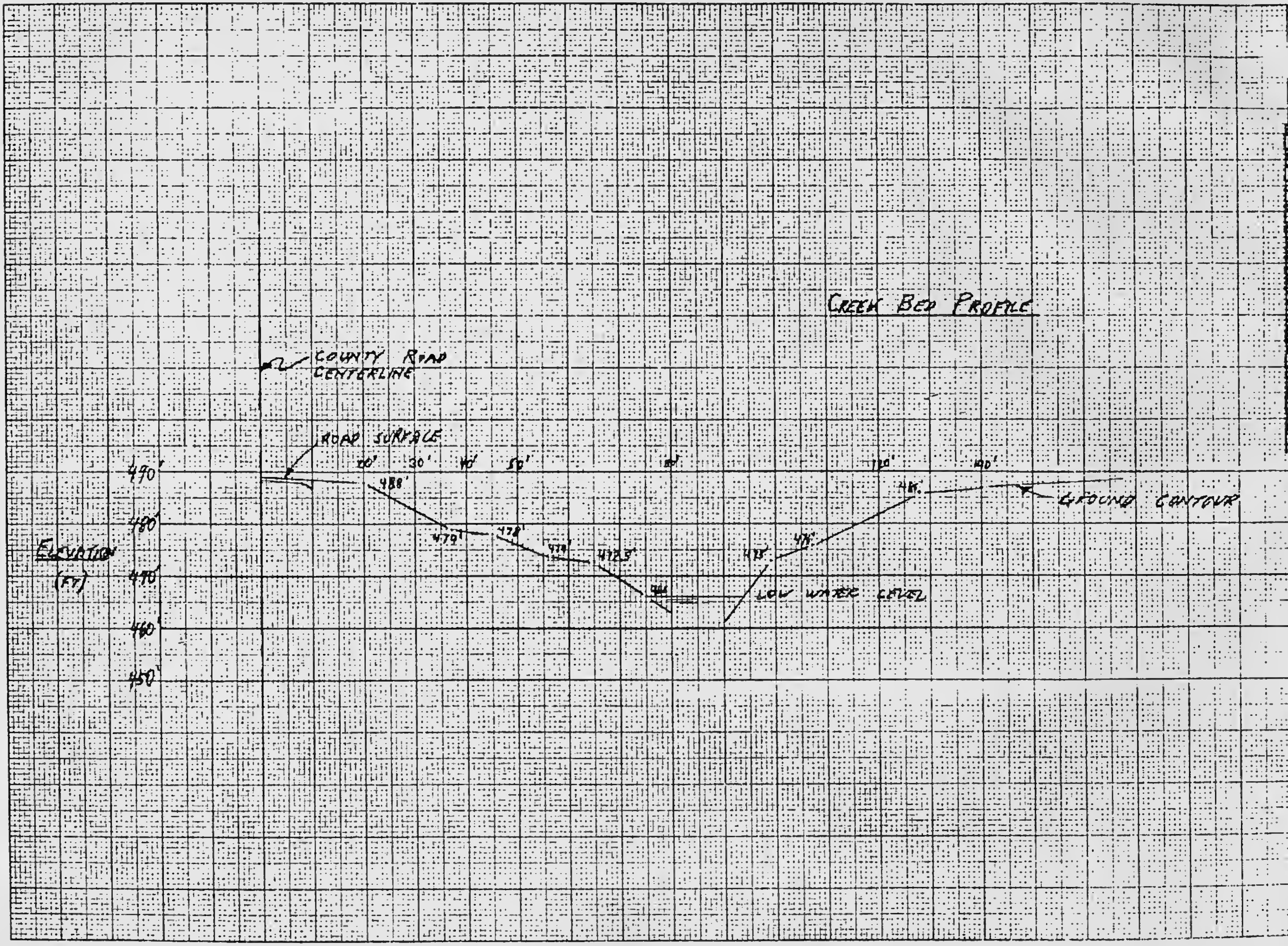
Exhibit 2 - Creek Bed Profile



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BRIDGE TYPE - SELECTION STUDY - BASED ON FIRST CONSTRUCTION COST

REFERENCE - MANUAL OF BRIDGE DESIGN PRACTICE
STATE OF CALIFORNIA - DIVISION OF HIGHWAYS

ASSUMPTIONS -
1. DECK WIDTH = 30'. STANDARD LOADING AS GIVEN BY MANUAL IS H-20-S16.
2. GIRDERS TO BE MADE IN SHOP AND CARRIED TO SITE.
3. SO STRUCTURAL STEEL OR PRESTRESSED CONCRETE GIRDERS CAN BE CONSIDERED.
4. 1 SIMPLE 100' SPAN IS ADEQUATE; TO BE COMPARED WITH 3 - 35' SPANS. COST DECREASE FOR POSSIBLE CONTINUITY WILL NOT BE REFLECTED.
5. COST OF GIRDERS AND ABUTMENTS WILL BE CONSIDERED ONLY.
6. ABUTMENT WILL BE CANTILEVER TYPE.
7. PIERS WILL BE HINGED TYPE.

COST SUMMARY

BRIDGE - TYPE SUPERSTRUCTURE	100' SPANS			3 - 35' SPANS		
	GIRDERS	ABUTMENTS	TOTAL COST	GIRDERS	ABUTMENTS & PIERS	TOTAL COST
ROLLED STEEL BEAMS				$13,000		
COMPOSITE GIRDER 36 WF SERIES				$10,800		
COMPOSITE WELDED STEEL GIRDERS	$21,600			$10,800		
PRESTRESSED CONCRETE "I" GIRDER	$9,810					

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COST CALCULATIONS - GIRDERS

1. 100' - SIMPLE SPAN - COMPOSITE WELDED STEEL GIRDER

THIS TYPE USED FOR SPANS OF 60' TO 140' LENGTH. (FROM CHART)
GIRDER SPACING 7'-6" (FROM CHART)
STRUCTURAL STEEL WEIGHT (FROM CHART) 30 PSF.
DECK AREA = 30 FT × 100 FT = 3,000 SF.
WEIGHT OF STEEL REQ'D = 30 PSF × 3,000 SF = 90,000 #
* COST @ $480/TON IS 90,000 × 480/2000 = $21,600 WORTH OF STEEL.

2. 100' - SIMPLE SPAN - PRESTRESSED CONCRETE "I" GIRDER

USED FOR SPANS 30' TO 120'. GIRDER SPACING 7'-0
DEPTH 5 FT. 4 GIRDERS REQUIRED.
QUANTITIES FROM MANUAL CHARTS

* PRESTRESSING STEEL	4(1,800#) = 7,200 # @ 55¢/#	= $3,950
REINFORCING BAR	4(1,800#) = 7,200 # @ 12¢/#	= 860
CONCRETE	4(450 FT³) = 1,800 FT³ = 67 CUBIC YARDS @ $75/CY	= 5,000
4 GIRDERS	TOTAL COST	$9,810 WORTH OF CONCRETE AND STEEL

3. 3-35' SIMPLE SPANS - ROLLED BEAMS

USED FOR SPANS 25' TO 75'. GIRDER SPACING 7'-6"
STRUCT. STEEL WT. FROM CHART 18 PSF
TIMES DECK AREA 3,000 SF = 54,000 #
* COST @ $480/TON = 54,000 × 480/2000 = $13,000 WORTH OF STEEL

4. 3-35' SPANS - COMPOSITE GIRDER - 36 WF SERIES

USED FOR SPANS 50' TO 80'. GIRDER SPACING 7'-6"
STRUCT. STEEL WT., SAY 15 PSF.
TIMES AREA 3,000 SF = 45,000 #
* COST @ $480/TON = 45,000 × 480/2,000 = $10,800 WORTH OF STEEL

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* Cost Figures were from company records. (footnote added by casewriter.)

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COST CALCULATIONS - GIRDERS (CONT.)

5. 3-35' SPANS - COMPOSITE WELDED STEEL GIRDERS

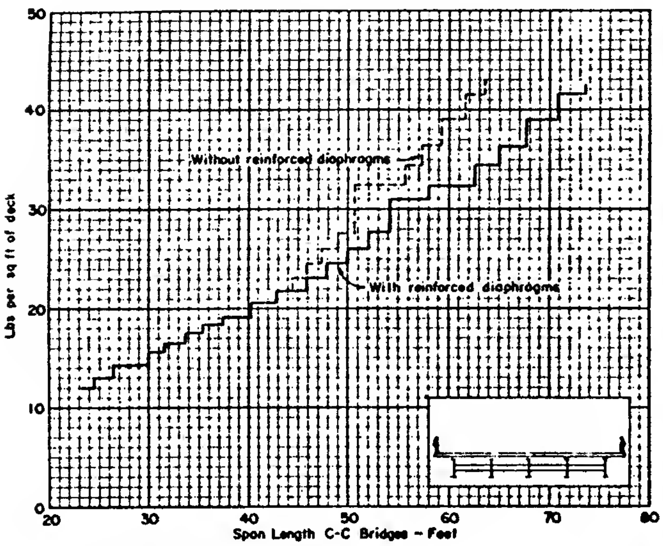
USED FOR SPANS 55' TO 140'. GIRDER SPACING 7'-6" TO 10'-6"

STRUCT. STEEL - ALTHOUGH FOR A 35' SPAN THERE WOULD BE A SLIGHT DECREASE IN WEIGHT PER SQ. FT., THIS PROBABLY WOULD BE OFFSET BY AN INCREASE IN FABRICATION LABOR COST. SO ASSUME COST OF STRUCT. STEEL IS SAME AS FOR CASE 4. ABOVE.

= $10,800

6. 3-35' SPANS - PRESTRESSED CONCRETE "I" GIRDERS.

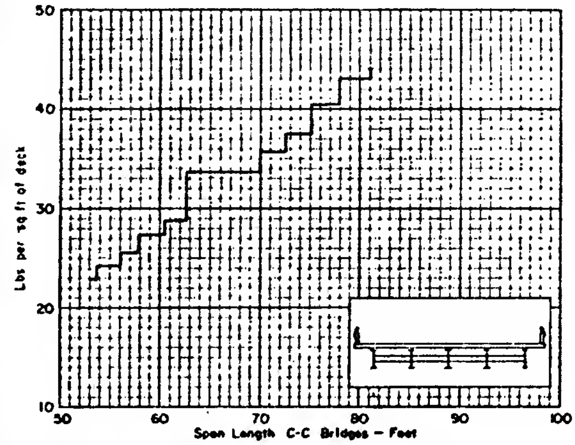
EXHIBIT 4. GIRDER COST ESTIMATING CHARTS
(From the "Manual of Bridge Design"
California Highway Transportation Agency)



Notes : Quantities based on 7'-6" girder spacing.
Weights of diaphragms included.

Loading : H 20 - S16 - 44
Structural steel : f = 18,000 psi
Reinforcing steel : f_s = 20,000 psi
Concrete : f_c = 1,000 psi

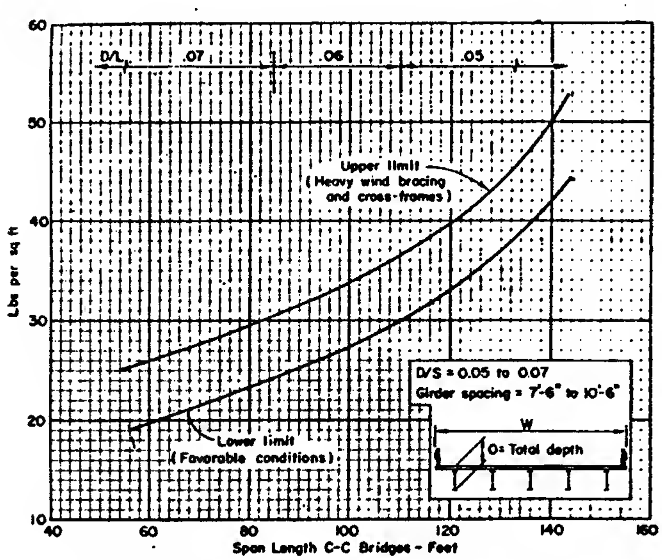
STRUCTURAL STEEL
SIMPLE SPAN ROLLED BEAM SUPERSTRUCTURE



Notes : Quantities based on 7'-6" girder spacing.
Weights of diaphragms and shear connectors included.

Loading : H 20 - S16 - 44
Structural steel : f = 18,000 psi
Reinforcing steel : f_s = 20,000 psi
Concrete : f_c = 1,000 psi

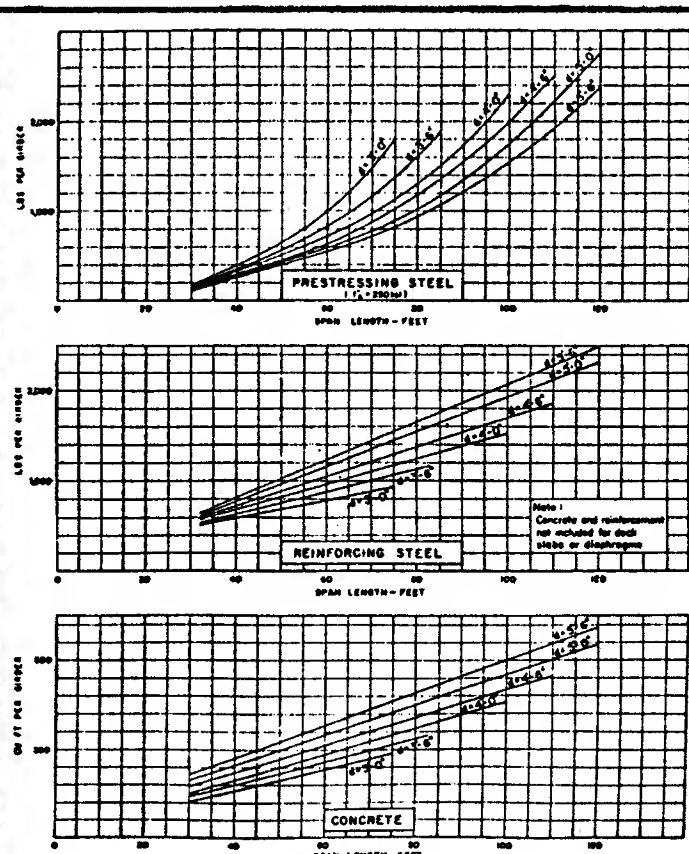
STRUCTURAL STEEL
SIMPLE SPAN COMPOSITE GIRDER SUPERSTRUCTURE
36WF SERIES



Notes : Weights of diaphragms, stiffeners, shear connectors, and minimum of wind bracing included.
D/L ratio approximates maximum economy

Loading : H 20 - S16 - 44
Structural steel : f = 20,000 psi
Reinforcing steel : f_s = 20,000 psi
Concrete : f_c = 1,000 psi

STRUCTURAL STEEL
SIMPLE SPAN COMPOSITE GIRDER SUPERSTRUCTURE
WELDED GIRDERS



STANDARD PRESTRESSED "I" GIRDER – 7'-0" GIRDER SPACING

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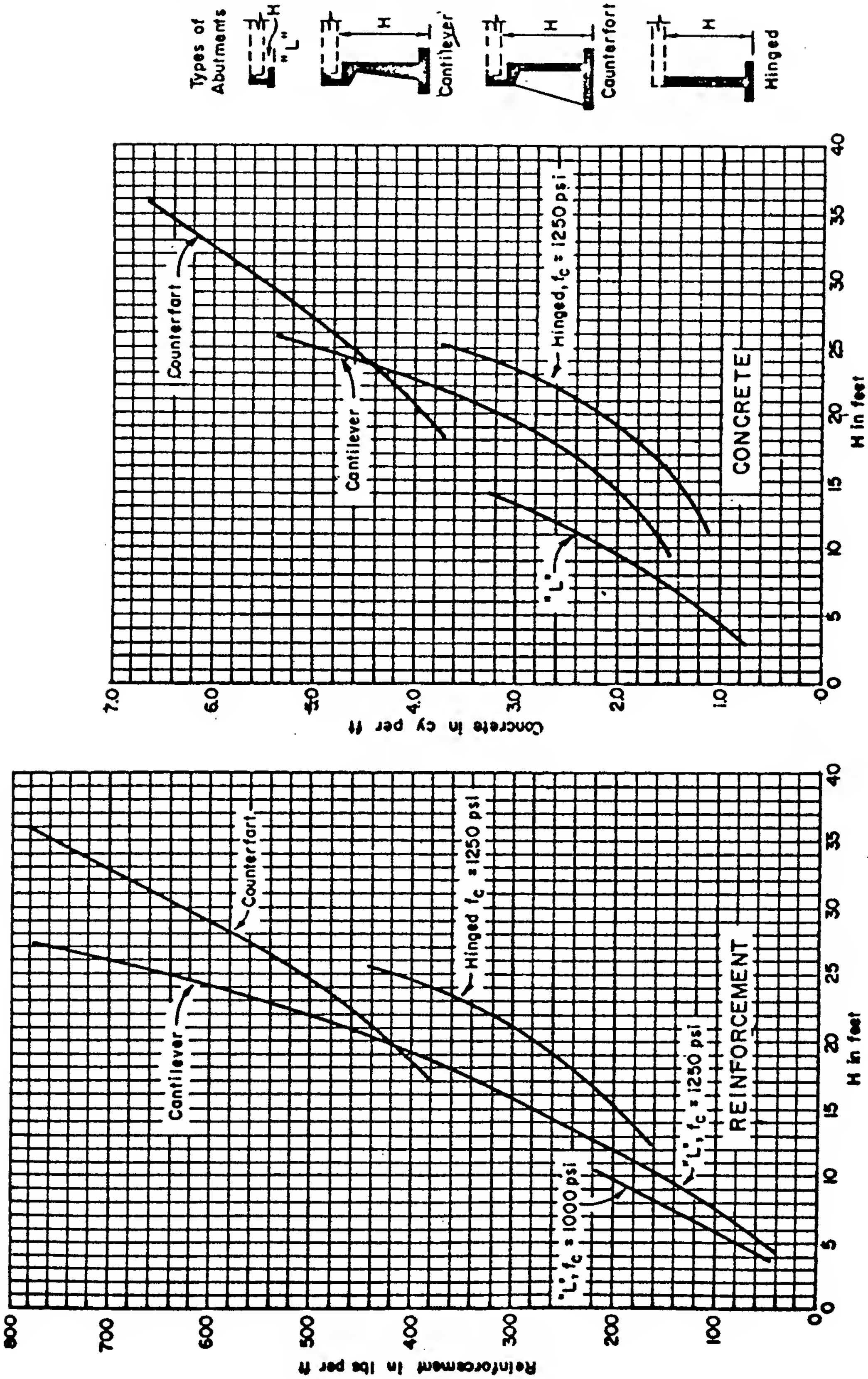
Exhibit 5 - Abutment Cost Estimating Charts

(From the "Manual of Bridge Design", California Highway Transportation Agency)



Notes : 1. To obtain the total quantity of concrete in cu. yds. and the total quantity of reinforcement in pounds for an abutment, multiply the values from the graphs by the rail to rail distance for the bridge in feet measured along the abutment layout line.

2. Footings and corner stub walls included. Tremie seals are not included

3. "H" is the average value for the abutment

4. Quantities good for spread and pile foundations. Use for T-beam and box girder.

Loading : H20-S16-44

f_s = 20,000 psi

f_c = Curves for 1,000 psi and 1,250 psi unless noted

ABUTMENTS